

CHARACTERISTICS AND APPLICATIONS OF ELECTROMAGNETIC SURFACE WAVE TRANSDUCERS

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Tom Szabo mentioned during his presentation that there is a great deal of similarity between the response of a meander line surface wave EMT and that of an interdigital transducer.¹ We have been investigating their common properties to see if they can be exploited for NDE applications.

The generation of bulk waves in delay lines is considered a problem for interdigital transducers,² but for NDE it might provide a convenient means of generating bulk waves propagating at an angle to the surface.³

The normal meander line transducer (Fig. 1) phase matches the wire spacing to the wavelength of the surface wave being generated. Surface waves are generated when the conditions shown in Fig. 2A are fulfilled. Here N is an odd integer. If the frequency is increased slightly, it is possible to phase match to a bulk wave propagating at an angle to the surface as is shown in Fig. 2B. At the lowest frequency of bulk wave generation the shear wave will propagate very close to the surface. It should be noted that this frequency is greater than the Rayleigh wave fundamental since $V_s > V_R$. As the frequency is increased, θ decreases from 90° and the shear waves sweep toward the normal to the surface. So you have a steerable bulk wave transducer.

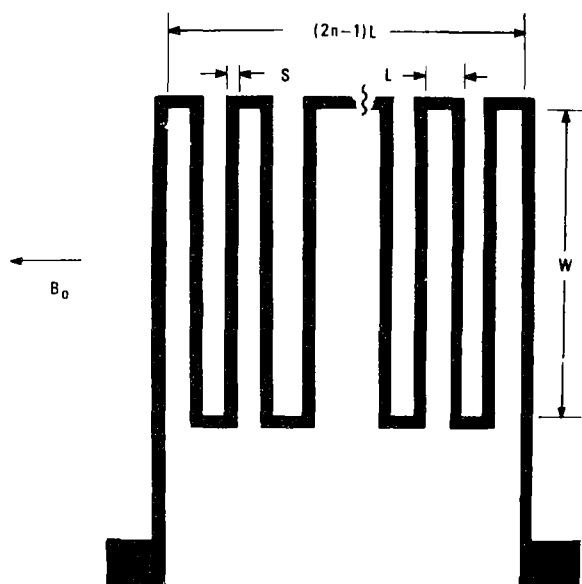


Figure 1. Meander Line EM Transducer

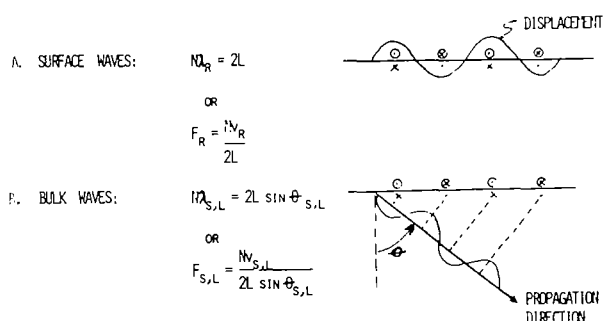


Figure 2. Meander line sound generation conditions
A) Surface waves
B) Bulk waves

The longitudinal wave velocity is approximately double the shear wave velocity. Thus, no longitudinal waves are generated until you reach double the onset frequency of the shear wave case. Therefore, it is possible to generate shear waves by themselves for frequencies up to twice the shear onset frequency and both longitudinal and shear waves above that frequency.

Now, let us look at one problem with these devices which is found when the bulk waves are propagated near the surface. In this case, the effective cross sectional area of the transducer is very small and the device looks essentially like a line source. A line source would emit a cylindrical wavefront instead of the desired narrow plane wave. Therefore, an enormous amount of beam spread near the surface is expected. The angle θ has to be less than 60° before you can get anything like a plane wave front out of the device.

We set up an experiment to determine if the transducer operated in the predicted manner. A 6" aluminum disk was cut in half (Fig. 3) with a meander line EMT in the middle and piezoelectric transducers on sliding mounts on the periphery. The first thing found was that when operated at the Rayleigh wave fundamental frequency bulk waves coming off normal to the surface were generated in addition to Rayleigh waves. We believe that the non-uniform magnetic field produced by the permanent magnet contributed to this bulk wave generation. Ordinarily with a uniform field, there would be almost complete cancellation of acoustic waves

propagating normal to the surface at the Rayleigh wave generation frequency due to the geometry of the transducer. In the permanent magnet case, there is a field gradient near the edges, so each region under the transducer sees a different field and the levels of excitation vary. Thus, there is an increase in the bulk wave generation from the edges. However, the level is still quite far down from the surface wave or phase-matched bulk wave levels.

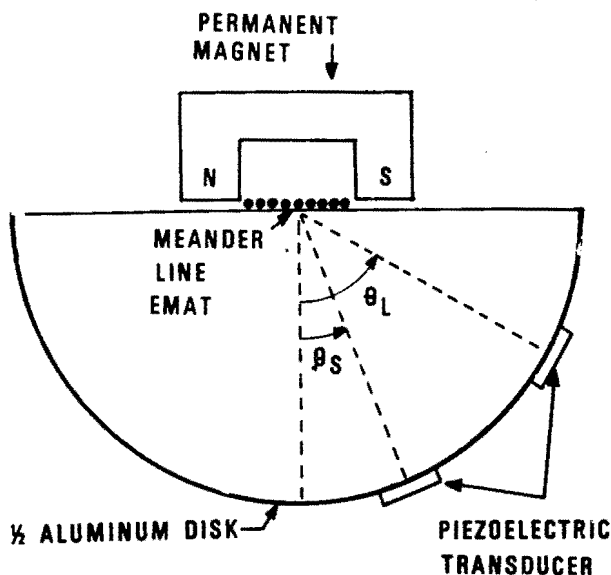


Figure 3. Experimental set-up for bulk wave propagation.

When the frequency was increased to look for the phase matched generation of bulk waves, they occurred at the predicted angles. This is shown in Fig. 4 for the shear waves, where the solid line is the theoretical prediction and the dots are experimental results. Note that the onset frequency is just above the Rayleigh wave fundamental as expected. The efficiency was also quite good in this case. For a single conversion, approximately 4dB was lost for angles down to 30° when the transducer was tuned correctly. It should be emphasized that this result only holds for the transducer used and with other devices there might be some variation in the efficiency.

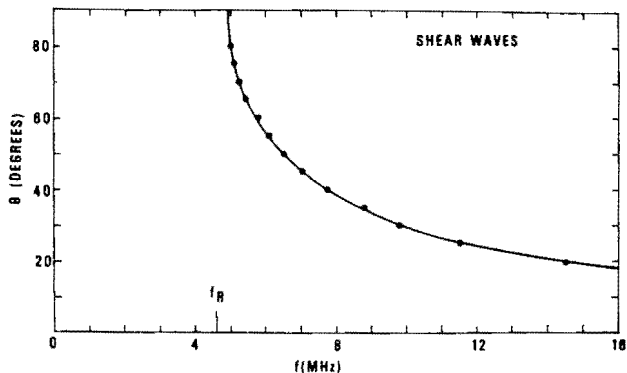


Figure 4. Dependence of bulk wave propagation direction on excitation frequency. The solid line is the theoretical prediction.

The longitudinal wave case gave equally good results (Fig. 5). The onset frequency is approximately double the Rayleigh wave frequency and again, there is an excellent agreement with theory. The efficiency decreased an additional 6dB per conversion from the shear wave efficiency due to the fact that the energy was split between the shear and longitudinal bulk waves at frequencies above the onset frequency for longitudinal waves.

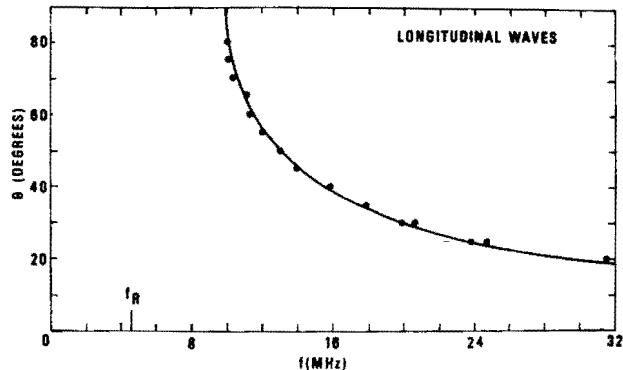


Figure 5. Dependence of longitudinal wave propagation direction on excitation frequency. The solid line is the theoretical prediction.

A second part of our work consisted of an attempt to use the signal processing capabilities of IDT's⁴ with EMT's. Our initial venture into this area was to design the chirp transducer coil shown in Fig. 6. The transducer output consists of an rf burst with a linear frequency modulation from 2 to 6 MHz. The reason for looking at such a device is to improve the range resolution of EMT's. Normally, with a multiturn EMT, the shortest possible pulse has a duration equal to the acoustic transit time across the device, because N transducers are excited in series. For the devices we have been using, this time is on the order of $3\ \mu\text{sec}$. If a second identical transducer is used to receive the $3\ \mu\text{sec}$ pulse, there is an additional pulse stretching of $3\ \mu\text{sec}$ due to the finite size of the receiver. This stretching is illustrated in Fig. 7 for a pair of 32 line, 5 MHz coils where the transmitter was driven by a $50\ \text{nsec}$ voltage spike. Note that the output is greater than $6\ \mu\text{sec}$ in duration. Thus, the range resolution of these devices is rather poor. The chirp transducer should improve the resolution dramatically due to the fact that such a device produces a significant output only when there is a spatial phase matching of the complete acoustic waveform and the coil.

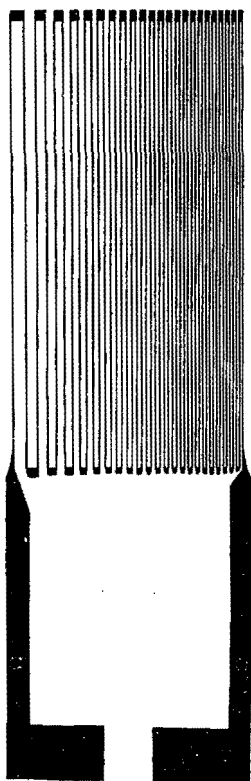


Figure 6. Linear F M Chirp E M Transducer

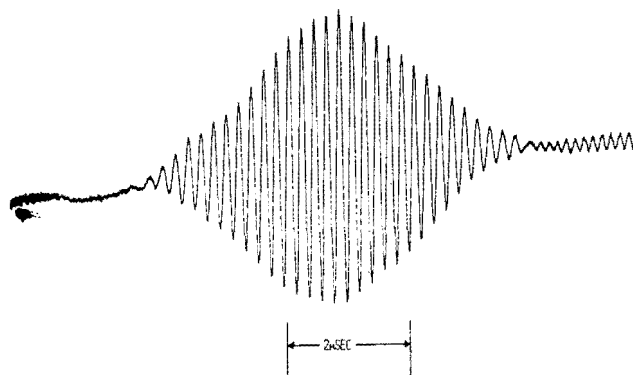


Figure 7. Response of a pair of 5 MHz EMT's to a $50\ \text{nsec}$ input pulse.

Now, let us look at the actual operation of these devices. Figure 8 shows the output of the 2 to 6 MHz chirp transducer when it is driven by a $50\ \text{nsec}$ pulse. Note that the duration of the output is of the order of $3.5\ \mu\text{sec}$. Figure 9 shows the compressed output pulse when the acoustic waveform shown in Fig. 7 is received by an identical chirp transducer. In this case, the duration is of the order of $0.25\ \mu\text{sec}$. To test the operation of these devices in a more realistic manner, a $1.09\ \text{mm}$ notch was cut into the end of an aluminum plate and the pulse excited chirp transducer was used in a pitch-catch mode. Figure 10 shows the output waveforms and the signal from the notch is very easily distinguished from the end face reflection. From this figure, it may be estimated that signals from reflectors of the order of $0.5\ \text{mm}$ apart would be resolvable provided the signals are of the same order of magnitude.

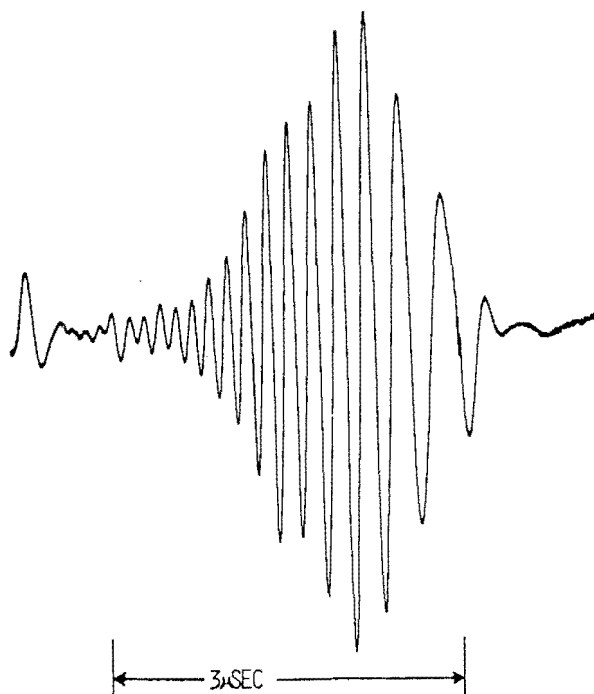


Figure 8. Output of Chirp Transducer driven by a $50\ \text{nsec}$ pulse input.

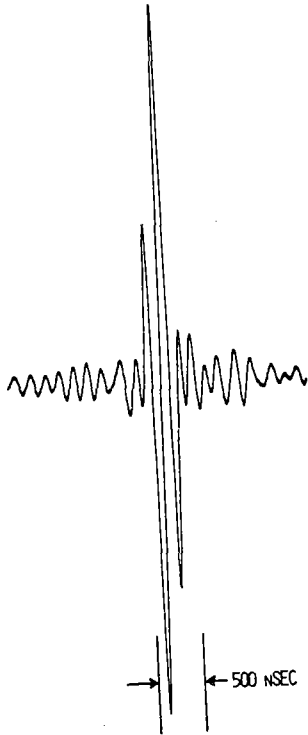


Figure 9. Response of Chirp Transducer to pulse shown in Fig. 8.

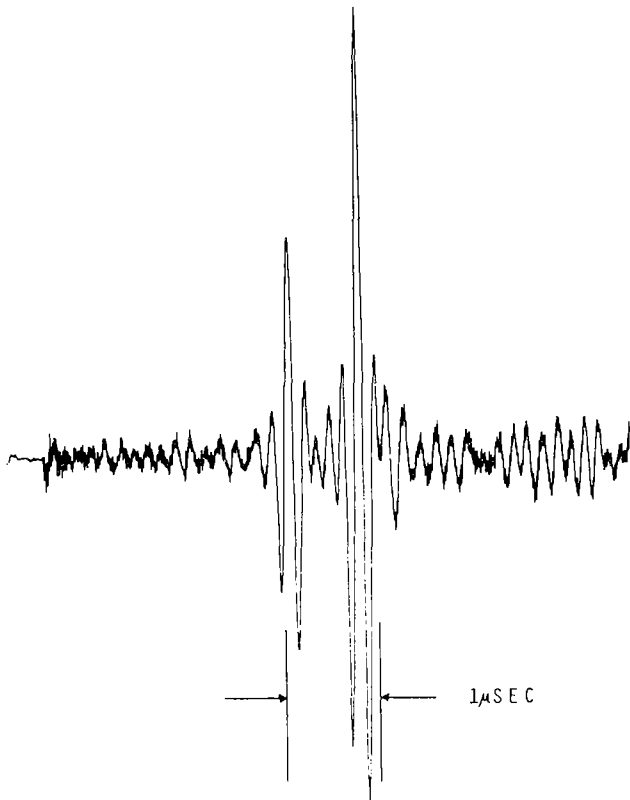


Figure 10. Resolution of signals from reflectors spaced 1.09 mm apart.

Some attempt has also been made to produce Gaussian waveforms with EMT's by tapering the lengths of the lines in the coil⁵. We have been able to reduce the near field amplitude fluctuations considerably, but a true Gaussian waveform has not been achieved. Work is still in progress in this area.

We also have put together a prototype NDE EMT transducer as shown in Fig. 11. The magnet consists of a pair of 0.5" x 0.5" x 1" Sm-Co bar magnets connected by a mild steel back plate with a 0.125" plastic spacer between them to form a quasi-horseshoe type magnet. The peak field is of the order of 5.5 kilogauss. A 1 mil thick mylar wear plate is used to cover the rf coil and protect it. If the surfaces being inspected are not too rough, this is quite adequate. If more protection is needed, 3 mils of mylar will only cause a 30% decrease in signal level at 5 MHz compared to the level using the 1 mil spacer.

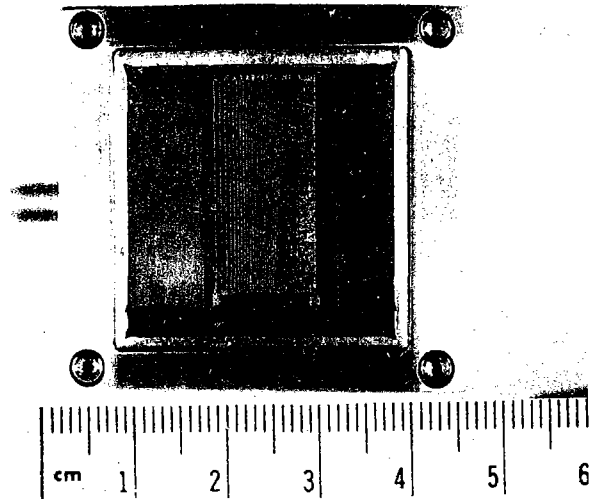


Figure 11. Photo of a prototype NDE EMT transducer.

In summary, we have been able to show that the bulk waves produced by a meander line EMT can be steered in a predictable fashion by varying the frequency. In addition, we have found that it is possible to obtain short pulses which give good range resolution using an EMT designed to produce a chirp output waveform. These advances in conjunction with the new small physical size have brought EMT technology close to the point where it can be applied to practical NDE problems.

References

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DISCUSSION

PROF. MACK BREAZEALE (University of Tennessee): The question I have is with regard to the chirp transducer. Is the idea that by utilization of a sweeping frequency one effectively sweeps a beam through the material?

DR. MORAN: No, that is not the chirp. We found that the single frequency Rayleigh wave devices could also be used to produce steerable bulk waves.

PROF. BREAZEALE: Single frequency?

DR. MORAN: Yes, the Rayleigh waves are single frequency. However, when such a device is operated at frequencies above the Rayleigh wave frequency, then bulk waves are produced and they can be steered by varying the frequency.

PROF. BREAZEALE: You choose a specific transducer for a specific frequency?

DR. MORAN: Yes, if you have a particular direction chosen for the wave. If you are interested in sweeping over a large angle, then you would have to sweep any transducer through a wide range in frequency.

PROF. BREAZEALE: So, you sweep through frequency and angle at the same time?

DR. MORAN: Yes.

PROF. VERNON NEWHOUSE (Purdue University): I'd like to follow up on that question. The chirp transducer, if I understand it correctly, is intended to give you better resolution.

DR. MORAN: For surface waves, yes. There should also be bulk waves generated, however.

PROF. NEWHOUSE: Right. And those bulk waves will go over a range of angles.

DR. MORAN: Yes, they should. However, since there is a staggered spacing to the lines, each pair of lines will generate bulk waves at a different angle at each frequency. Most of the directed energy will be concentrated in the Rayleigh wave.

PROF. K. LA KIN (University of Southern California-Los Angeles): I have a comment regarding bulk wave generation. The surface wave transducer, if you have a small number of interdigital electrodes as lines, will always phase match to the bulk modes.

DR. MORAN: Yes.

PROF. LAKIN: It's not necessarily an anomaly on the edge of the surface wave transducer.

DR. MORAN: This is a 32-line transducer I was looking at. Also, the anomalous bulk waves were generated at the edge, were rather broadband, and were not phase matched. They were in addition to the phase matched waves.

PROF. NEWHOUSE: Last question.

DR. SY FRIEDMAN (Naval R&D Center): Is it possible by design to lower the threshold frequency for shear waves?

DR. MORAN: Yes, you just increase the spacing between the lines in the coil.

PROF. NEWHOUSE: Have you ever thought of producing focussing effects by trying to mess around with your magnetic field?

DR. MORAN: It's easier to change the coil. A coil with curved lines will produce a focussed beam.

DR. NEWHOUSE: You might even be able to produce dynamic focussing if you start changing your magnetic field.

DR. MORAN: We are using permanent magnets right now. To get a varying field you would need an electromagnet which would be bulkier and also would give a smaller field in most cases.